AVCO EVERETT RESEARCH LABORATORY
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50 kW PULSED ULTRAVIOLET LASER

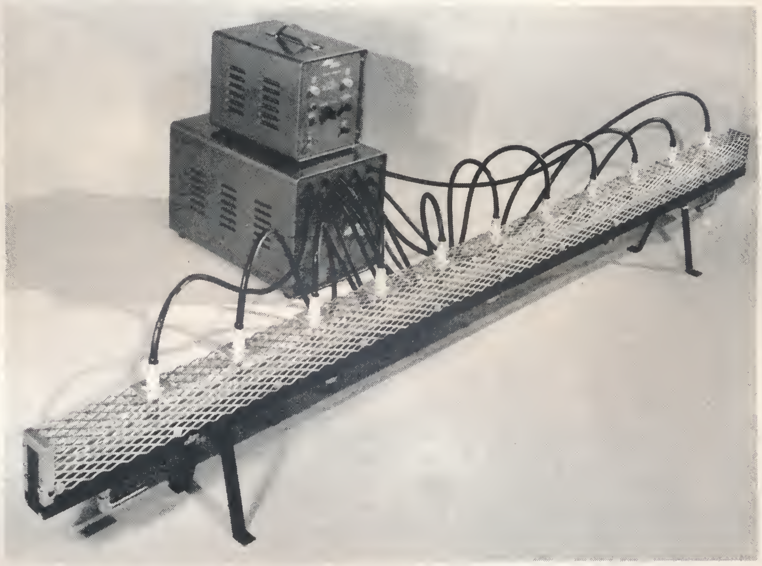


Fig. 1

The pulsed nitrogen laser developed by Avco Everett Research Laboratory, which is capable of 50 kW peak power output in the 3371 Å ultraviolet wavelength, is an outgrowth of the Laboratory's intensive program of research in gas lasers.

Performance parameters of the 50 kW device are given in Table I.

TABLE I
Avco 50-kW Ultraviolet Pulsed Nitrogen Laser

Peak Ouput Power	50 kilowatts
Pulsewidth	10-20 nanoseconds
Pulse Repetition Rate	1-10 pps (variable)
Synchronization	Less than 1 μ s
Output Wavelength	3371 Å (ultraviolet)
Output Bandwidth	$\lesssim$1 Å
Output Beam Dimensions	1/8" x 1-1/8"
Beam Divergence	1 milliradian in 1/8" dimension
	10 milliradians in 1-1/8" dimension
Discharge Channel	Rectangular cross field - 2 meters in length
Mirror	Single mirror; super-radiant mode
Gas	Commerical grade N_2
Resonator	Not required
Power Requirements	2 ma at 20 kV (40 W)
Mounting	Table top
Gain	75 dB/meter of the channel

This laser, which is now commercially available, is based on an experimental pulsed nitrogen unit that has produced peak powers of more than 300 kW in the laboratory. While pulse rates of 1 to 10 pps are now available, experimental models of this laser have demonstrated pulse rates of 100 pps, and diffusion rate calculations have shown that 1000 pps are theoretically possible.

The Avco laser is basicially a very simple and rugged device, thanks largely to its unique crossed-field geometry. The driving electric field is applied across the discharge channel perpendicular to the output beam. This permits use of high electric field over a large volume of gas with easily manageable voltages. The complete laser assembly includes the discharge channel, capacitor bank, transmission lines, spark switch, and trigger control box.

Since the pulsed nitrogen laser emits self-terminating pulses of 10 to 20 nanoseconds' duration, there is no need for Q switching. Output pulse can be synchronized to less than 1 μ s of the input trigger pulse. The extremely high power amplification (75 dB/meter of channel) permits operation with only one pre-aligned mirror and no resonator.

AVCO 50 kW ULTRAVIOLET PULSED NITROGEN LASER

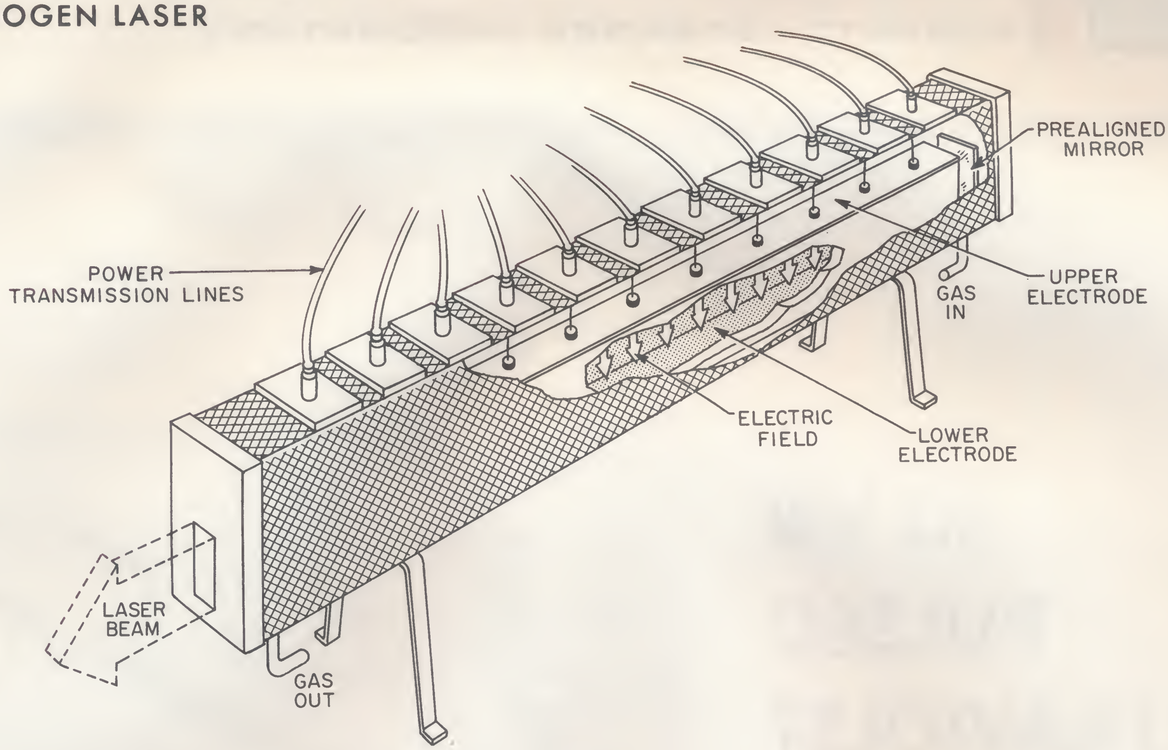


Fig. 2

Figure 2 shows a cutaway schematic drawing of the crossed-field device in which the power flows from a a capacitor through transmission lines to an upper electrode which is an aluminum strip two meters long. A U-shaped aluminum channel serves both as structural support for the device and as the other electrode. The discharge takes place between dielectric side walls. On the short time scales required by this laser, the current distribution is essentially inductance controlled and extremely uniform discharges can be produced along the entire length of the two-meter discharge channel.

Due to the extremely high optical gain and the short pulse duration, the best arrangement for maximum power output was found to be a plane mirror at one end of the discharge channel with the other end left open. With no mirror at either end the device has sufficient gain to produce a super-radiant beam which has a divergence angle equal to the discharge channel width divided by the discharge channel length. The effect of the mirror is to double the effective length and thereby decrease the beam divergence. A beam divergence of one milliradian has been produced in this way.

RESEARCH BACKGROUND

The performance characteristics of the 3371 Å molecular nitrogen laser have been studied both experimentally and theoretically. The population inversion is produced for 20 nanoseconds in the second positive band system of molecular nitrogen during a high current, high voltage, pulsed discharge. Laser pulses of more than 300 kW with a beam divergence of 10^{-3} radians have been produced in a 2-meter-long device in which the applied electric field and the discharge current are perpendicular to the direction of the simulated emission. Maximum power output was obtained with a plane mirror at one end of the discharge channel with the other end left open. For discharge lengths less than 80 cm and power levels less than 10 kW the power gain is 75 dB per meter. For lengths longer than 80 cm the device saturates and the power increases linearly with length at a rate of 2 kW per cm^3. The efficiency when saturated was .6%.

A theory has been devised which accounts for most of the experimentally observed features. Direct electron impact excitation of the triplet states $C^3\pi$ and $B^3\pi$ is the mechanism used to overpopulate C with respect to B for times of the order of the 40 nanosecond radiative lifetime of C. The calculated laser pulse width and pulse amplitude agree with the experimentally determined values. The efficiency is somewhat higher since not all the electron energy loss mechanisms are included in the electron energy equation.

PARTIAL ENERGY LEVEL DIAGRAM FOR N_2

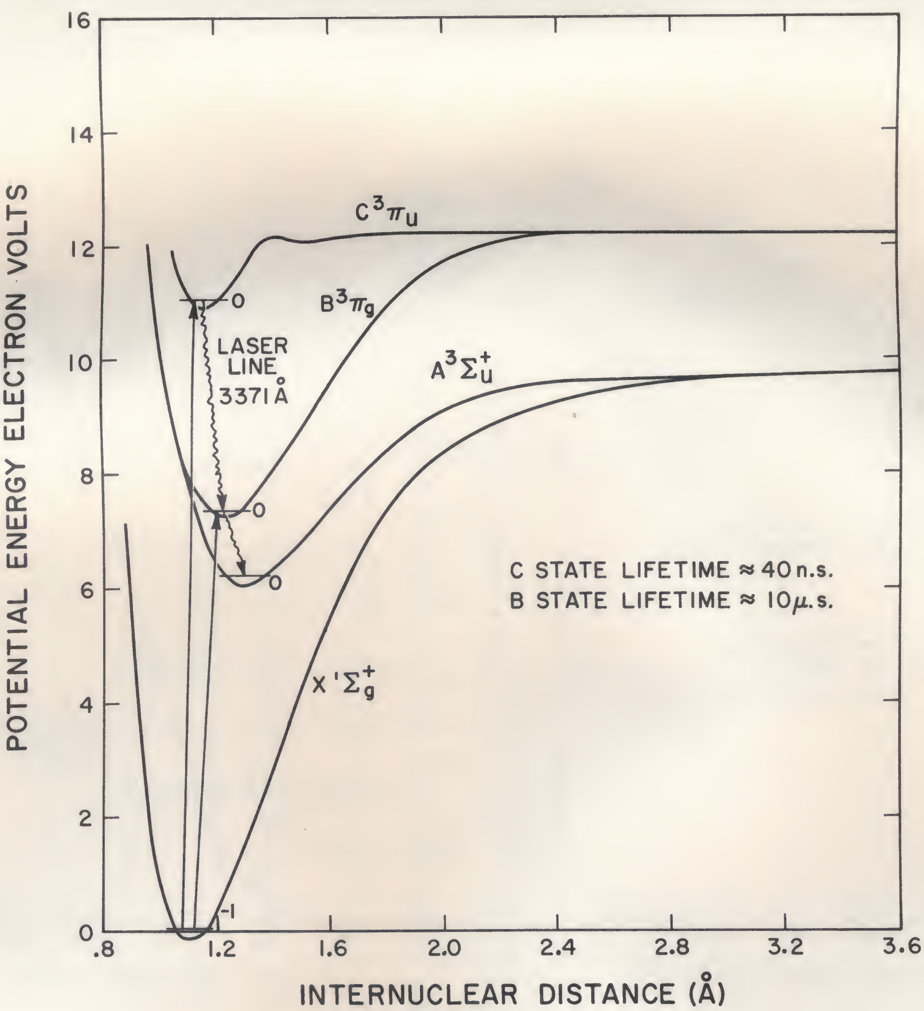


Fig. 3

Figure 3 is a partial energy level diagram for the nitrogen molecule showing in particular the relevant energy levels for this laser which operates on the (0,0) transition of the second positive band system (3371 Å). The radiative lifetime of the upper C state is 40 nanoseconds, which is much shorter than the 10 microsecond lifetime of the lower B state. These lifetimes are in exactly the wrong ratio for steady-state laser operation. However, if the rate of excitation into the C state is larger than into the B state, an inversion and laser action can be obtained for a time less than the lifetime for transitions from C to B. The Frank - Condon factors for overlap of the C and B states with the ground state indicate that the basic cross - section to the B state would be about a factor of 10 less than that for the C state.

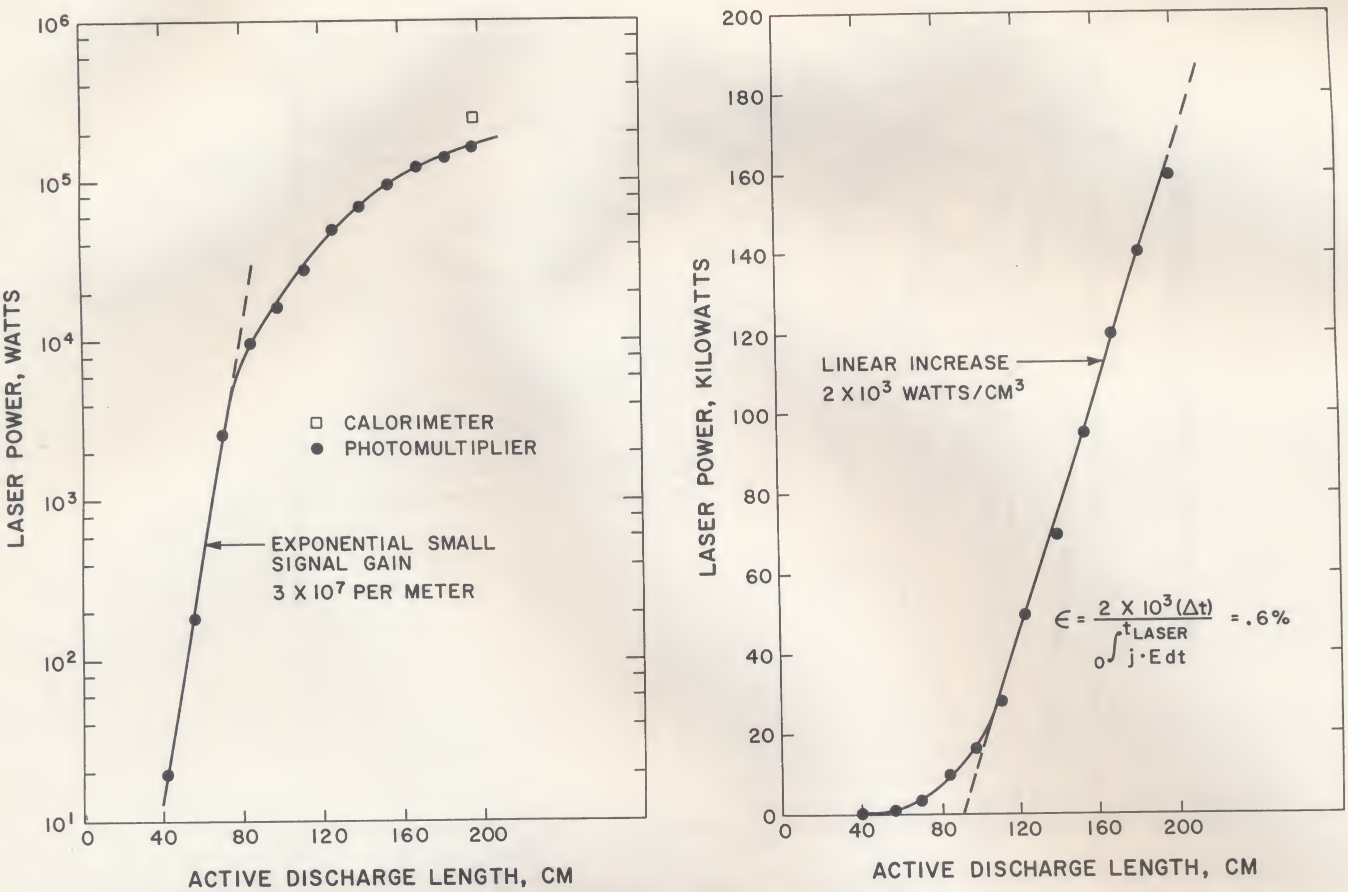
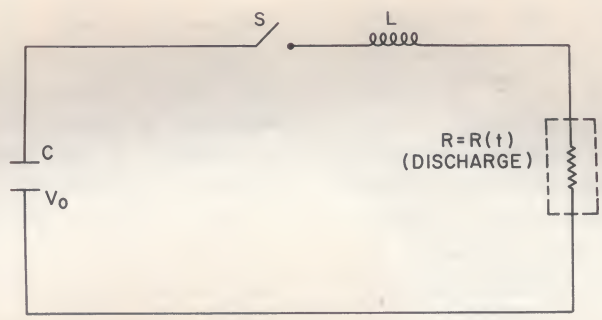


Fig. 4

Quantitative data on the peak power output of the pulsed nitrogen laser vs active length of discharge are shown in Fig. 4 as both a semilog and a linear plot for a typical set of circuit parameters and crossed-field discharge geometry. On the semilog plot for active lengths less than 80 cm and peak power levels less than 10 kW, the power output is seen to increase exponentially with length. In this small signal domain the power gain is 75 dB per meter. For longer discharge lengths the power output saturates and increases linearly with length to 160 kW for the total length of 200 cm. On the linear plot the slope of the straight line portion indicates a saturation power of 2×10^3 watts/cm^3. These data were taken with a calibrated and suitably attenuated photomultiplier. The maximum power output was also measured with a "rat's nest" calorimeter which gave a value 50% higher than the photomultiplier measurements.

The efficiency on the slope of the linear increase is estimated by integrating the total electrical power per unit volume put into the gas up to the time the laser pulse terminates. On this basis the efficiency is .6%.

CIRCUIT MODEL, N_2 LASER THEORY



CIRCUIT EQUATIONS

$$V_c = LA\frac{dj}{dt} + j\rho\ell ; \qquad \frac{dV_c}{dt} = -\frac{jA}{C}$$

IONIZATION RATE EQUATION

$$\frac{dN_e}{dt} = N_e N_o \overline{\sigma_i v_e}$$

EXCITATION RATE EQUATIONS

$$\frac{dN_c}{dt} = N_e N_o \overline{\sigma_{oc} v_e} - \frac{N_c}{\tau_c} - P$$

$$\frac{dN_b}{dt} = N_e N_o \overline{\sigma_{ob} v_e} + \frac{N_c}{\tau_c} + P - \frac{N_b}{\tau_b}$$

ELECTRON ENERGY EQUATION

$$\frac{d}{dt}\left(3/2\, N_e k T_e\right) = \rho j^2 - N_e N_o \overline{\sigma_i v_e}\, E_i - \sum_k N_e N_o \overline{\sigma_{x_k} v_e E_k}$$

Fig. 5

The pulsed nitrogen laser is a device whose performance can be calculated theoretically. The basic model assumed for the calculation is shown in Fig. 5 and consists of a series RLC circuit. The capacitor is charged to a voltage V_o and the switch S is closed at $t = 0$, initiating the discharge in the plasma channel (indicated by the time dependent resistance R (t)). The excitation and ionization rates are computed as a function of time via the equations shown in the same figure. The relevant cross sections for ionization and excitation are known, as is the electron mobility for nitrogen.

In the circuit equations V_c is the voltage on the capacitor, j is the current density, $\rho = \rho\,(kT_e, N_e)$ is the plasma resistivity, ℓ is the discharge length and A is the discharge area. In the rate equations N_e is the electron density, N_o is the molecular nitrogen ground state density which is not significantly depleted during the pulse, N_c and N_B are the densities and τ_c and τ_B are the radiative lifetimes of the C and B states respectively. The quantities σ_v are the cross-section velocity products which have been averaged by integrating over a Maxwellian electron velocity distribution to obtain excitation and ionization rates as a function of electron temperature. In the electron energy equation E_i is the ionization energy and E_k represents electron energy loss by excitation of electronic and vibrational levels. The quantity P in the excitation equations is the saturated laser power and is computed such that $N_C = N_B$ is maintained. The small signal gain can also be computed from this set of equations by setting $P = 0$ and calculating $N_C - N_B$, the inversion density.

APPLICATIONS

Some suggested applications for the Avco pulsed nitrogen laser include:

Physics: The scattering cross-section for Raman and Rayleigh scattering varies as the reciprocal of the fourth power of the wavelength; this means that an ultraviolet light source of 50 kW is roughly equivalent to a 10 MW red or infrared source. Thus, the pulsed nitrogen laser is an excellent light source for spectroscopic measurements utilizing Rayleigh and Raman scattering. It is also useful for double photon experiments, second harmonic generation, etc.

Chemistry: Studies of photochemical reactions, flourescence, flash photolysis, utilizing 20 nanosecond pulses of 50 kW 3371 Å ultraviolet energy. Pulse rates of 1 to 10 pps are available; 100 pps have been demonstrated in laboratory experiments.

Biology and Medicine: As a source of high energy ultraviolet pulses, the pulsed nitrogen laser can be used for basic studies of molecular bonding energies, selective cell destruction, and other biological and medical effects.

Meteorology: The 50 kW pulsed nitrogen laser can be used to study atmospheric constituents as a function of altitude by means of Raman scattering. It can be employed as a ceilometer and, in conjunction with a laser of different wavelength, can be employed to measure the particle size distribution in clouds. It may also be effective in detecting Clear Air Turbulence.

Optical Radar: Because of its high peak power and short pulse width, the laser can attain range and range-rate tracking resolution of 20 feet (or better, by using leading edge slope technique). Its high repetition rate increases its suitability for radar applications.

Photography: As a source of high energy ultraviolet pulses, the nitrogen laser can be employed for high speed photography, schlieren and shadowgraph measurements, etc.

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